ENERGY BALANCE OF HIGHLY CONTAMINATED SURFACE FLASHOVER ON THIN FILMS

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Abstract

The ability to produce controllable plasmas is usually confined to high energy applications. Many applications, however, would greatly benefit from a reduction of this input energy. This paper examines a new, low energy method to generate a plasma utilizing the mechanism of surface flashover on thin metallized films. This method of plasma generation was unique in that a controllable plasma was generated while requiring less than 5 J of energy. The plasma was produced by applying an impulse voltage of 2.5 kV to a sample of polypropylene film coated with an aluminum metallization on one surface. The resultant flashover liberated only a small percentage of the metallization off of the polypropylene film. The energy required to create the plasma was determined by evaluating the time integral of the voltage and current product then comparing that quantity to the amount of energy required to liberate the already removed aluminum metallization from the polypropylene film. It was found that the energy required to vaporize the aluminum was about an order of magnitude less than the total amount of energy that went into the film. After taking this into account, the amount of energy required to generate and sustain the plasma was determined. This low energy plasma initiation could have interesting applications as a low power light source or be exploited for other avenues of inquiry.

I. INTRODUCTION

The film that was used consists of a thin polypropylene layer coated with aluminum metallization. The dimensions of the film used in the experiments are shown in Figure 1. The advantages of this geometry for plasma generation applications are twofold. First, the polypropylene layer provides robustness and workability that are uncharacteristic of round wires of equal volume. Second, the thinness of the aluminum leads to a low heat capacity while still allowing large currents to pass through it. This means that sufficiently high current densities will vaporize the metallization, which in turn helps to generate the plasma. Figure 2 shows a typical film sample after a pulse was discharged through it.

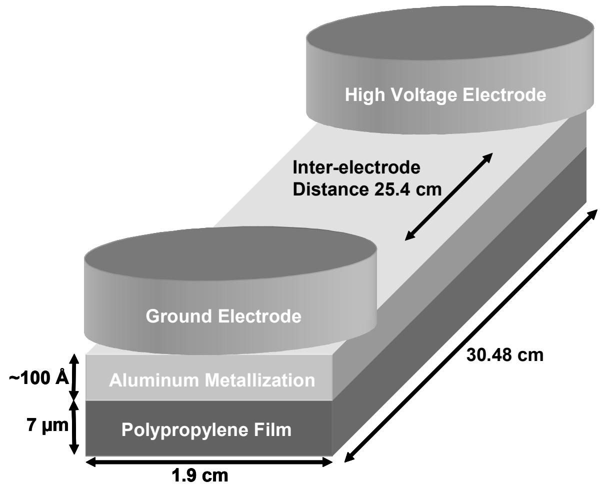

Figure 1. Representation of metallized polypropylene film under test (electrodes are stainless steel)

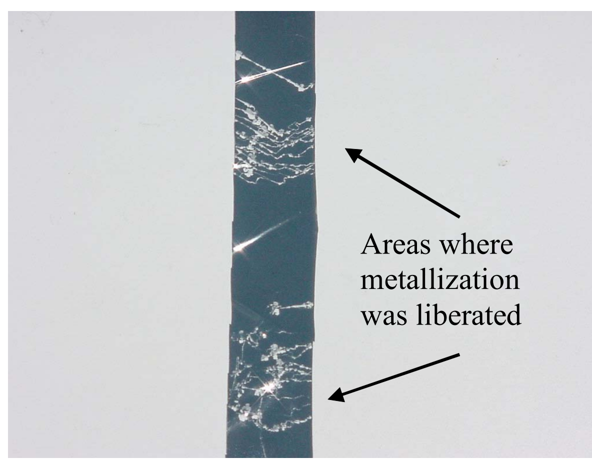

Figure 2. Picture of metallized polypropylene film sample after flashover

The lighter colored areas are where the metallization was vaporized. The amount of energy required to vaporize the aluminum was calculated using basic thermodynamic principles. Assuming the specific heat of aluminum is temperature independent due to the speed at which the process occurs, the expression for the heat energy liberated is:

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14. ABSTRACT

The ability to produce controllable plasmas is usually confined to high energy applications. Many applications, however, would greatly benefit from a reduction of this input energy. This paper examines a new, low energy method to generate a plasma utilizing the mechanism of surface flashover on thin metallized films. This method of plasma generation was unique in that a controllable plasma was generated while requiring less than 5 J of energy. The plasma was produced by applying an impulse voltage of 2.5 kV to a sample of polypropylene film coated with an aluminum metallization on one surface. The resultant flashover liberated only a small percentage of the metallization off of the polypropylene film. The energy required to create the plasma was determined by evaluating the time integral of the voltage and current product then comparing that quantity to the amount of energy required to liberate the already removed aluminum metallization from the polypropylene film. It was found that the energy required to vaporize the aluminum was about an order of magnitude less than the total amount of energy that went into the film. After taking this into account, the amount of energy required to generate and sustain the plasma was determined. This low energy plasma initiation could have interesting applications as a low power light source or be exploited for other avenues of inquiry.

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$$Q = C_{Al} V_{Al} \rho_{Al} \Delta T + H_V V_{Al} \rho_{Al} \qquad (1)$$

where C_{Al} is the specific heat of aluminum, V_{Al} is the volume of the vaporized aluminum, ρ_{Al} is the density of aluminum, ΔT is the change in temperature (room temperature to boiling), and H_V is the heat of vaporization of aluminum [1]. The volume of the vaporized metallization is explained in [2] and the other numbers are readily available [3,4]. The energy Q is therefore determined to be (0.9 J/gK)*(3.048x10^{-6} cm^3)*(2.70 g/cm^3)*(2714 K – 295 K) + (10852 J/g)*(3.048x10^{-6} cm^3)*(2.70 g/cm^3) = 0.107 J. Following sections will discuss the evaluation of the time integral of the current and voltage waveforms. By comparing this value with the energy required to vaporize the aluminum, the energy required to create and sustain the plasma was determined.

II. EXPERIMENTAL SETUP

A preliminary experimental setup consisting of the film and electrode configuration (shown in Figure 1), and a capacitive discharge power source shown in Figure 3 was developed to carry out this study. The pulser contains a 2.6 µF capacitor in parallel with a 20 MΩ bleed resistor to safely discharge the capacitor. The output of the pulser was connected to two stainless steel electrodes as depicted in Figure 1. Each electrode is 2.54 cm in diameter with the spacing between the high voltage electrode and the ground electrode measuring 25.4 cm. The dimensions of the metallized polypropylene film are shown in Figure 1.

To perform the experiment, the capacitor was charged to 2500 V$_{dc}$. The open circuit between the pulser and the metallized polypropylene film was closed via an NMOS controlled thyristor. Current measurements were taken with a small Pearson current transformer placed around the high voltage lead going to the film. Voltage measurements were accomplished by incorporating a Tektronix P6015 probe connected to the high voltage lead of the capacitor [2].

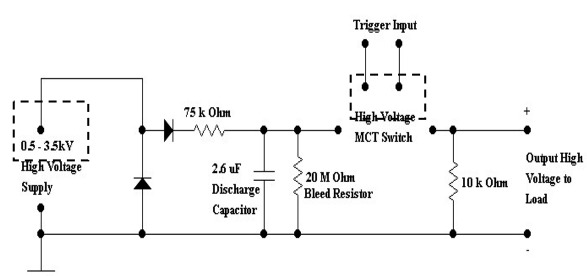

Figure 3. Schematic of capacitive discharge pulser

III. EXPERIMENTAL RESULTS

When 2.5 kV was applied to the sample, it yielded waveforms typical of an RC decay profile that is critically damped. Figure 4 and Figure 5 represent typical current and voltage waveforms, respectively.

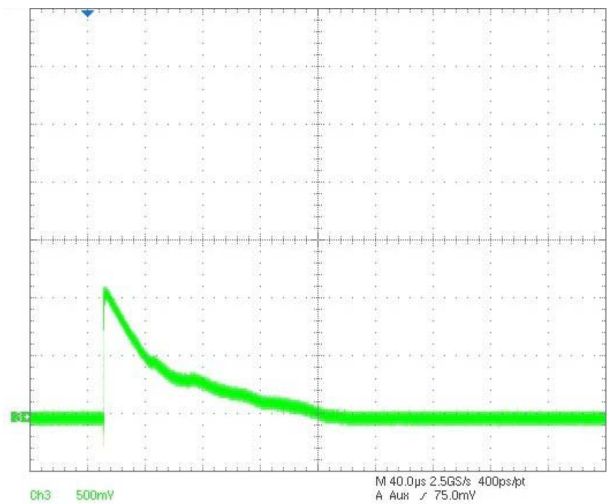

Figure 4. Typical current pulse recorded from thin metallization explosion

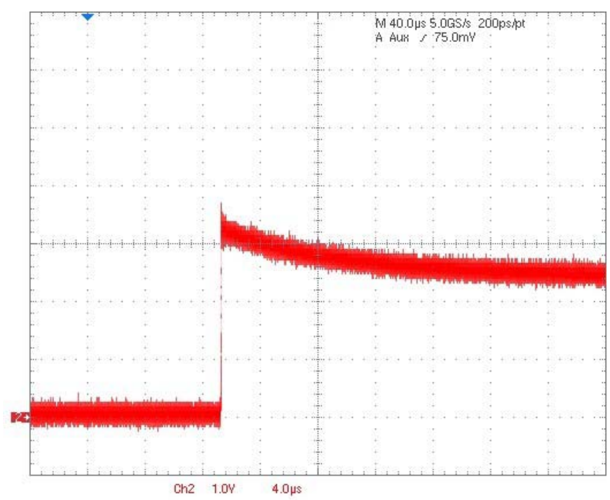

Figure 5. Typical voltage profile of thin metallization explosion

By assuming that both waveforms are in the form of an exponential decay, they can be modeled with expressions that can then be integrated over time to yield the total amount of energy that went into the sample. The waveforms will therefore be of the form

$$V(t) = (V_p - V_f)e^{-3t/\tau} + V_f \qquad (2)$$

$$I(t) = I_p e^{-3t/\tau} \qquad (3)$$

where V_p and I_p are the peak voltage and peak current, τ is the duration of the pulse, and V_f is the voltage on the capacitor after the pulsed discharge occurs. The "3" in Eqs. 2 and 3 ensures that the decay is at least 95% complete when t is equal to the time duration of the pulse. From Figures 4 and 5, these values are determined to be V_p=2500 V, I_p=8.5 A, τ=160 μs, and V_f=2350 V. The total energy is then given by

$$E = \int_0^\infty V(t)I(t)dt \,. \tag{4}$$

When the experimental values were put into the equations, the evaluation of the time integral yielded an energy of 1.05 J. This is an order of magnitude greater than the energy required to vaporize the metallization, yet is much less than the kilojoules of energy that go into generating plasmas from round wires [5].

A more accurate energy measurement can be taken by saving the individual current and voltage data points and performing a numerical integration on the product of the two. From a total of seventeen experiments performed, the average energy turned out to be 1.24 ± 0.60 J. This energy is close to the estimated energy, yet the percentage uncertainty is almost 50%. While the total energy is fairly consistently under 2 J, it varied by up to 0.5 J from experiment to experiment. One possible explanation for this is that the thickness of the film could be different for each sample. Each sample was cut from a large roll, and it is possible that the thickness of one part of the roll is different from other parts. The data that was taken showed a systematic increase in energies from sample to sample, which could be a reflection of a slowly varying thickness of the metallization on the roll of film. If the energies had been randomly distributed, this could have been ruled out as a source of the uncertainty.

V. CONCLUSIONS

This paper has discussed a new and novel approach for generating low energy plasmas. Calculations using the current and voltage waveforms showed that the average total energy going into the system is approximately 1.24 J. Then a theoretical calculation of the energy required to vaporize the metallization showed that it comprises about a tenth of the total energy put into the system. Subtracting the amount of energy required to vaporize the aluminum from the energy going into the system yields the maximum value for the energy required to generate and sustain the plasma. However, it is known that there are other sources of energy loss, including ohmic heating and light radiation. This further reduces the energy required to generate and sustain the plasma and proves that controllable plasmas can be created with very low energies. An even higher degree of control over the plasma could therefore make this a very valuable technology, especially if used as a light source or an ignition source for energetic materials. Future studies aim to more accurately control the location of the plasma generated and to quantify the remaining avenues of energy loss.

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